

# **Reconstructing Hurricane Irma in Miami under Climate Change: Linking Hydrodynamics, Coastal Flooding, Erosion and Risk**

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**International Workshop on Waves,  
Storm Surges and Coastal Hazards**

**Santander  
25/09/2025**

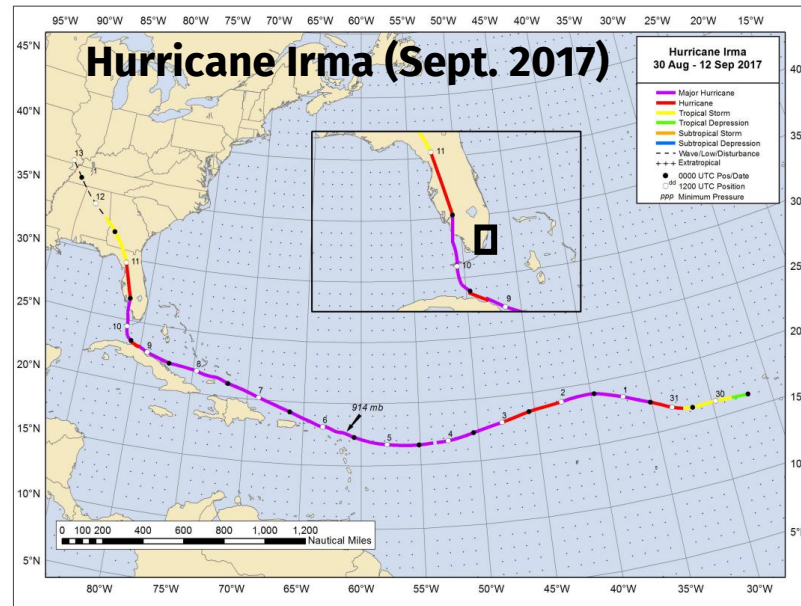
# CONTEXT: MIAMI AND HURRICANE IRMA (2017)

Tropical cyclone-induced impacts and risks are exacerbated by climate change, via sea-level rise (Vitousek et al., 2017; Fox-Kemper et al., 2021) and shoreline retreat (Vousdoukas et al., 2020)



## MIAMI:

- Interior bay lies below 1 m above sea level
- ~2.7 million people in Miami-Dade County
- High economic value
- Frequent hurricane activity

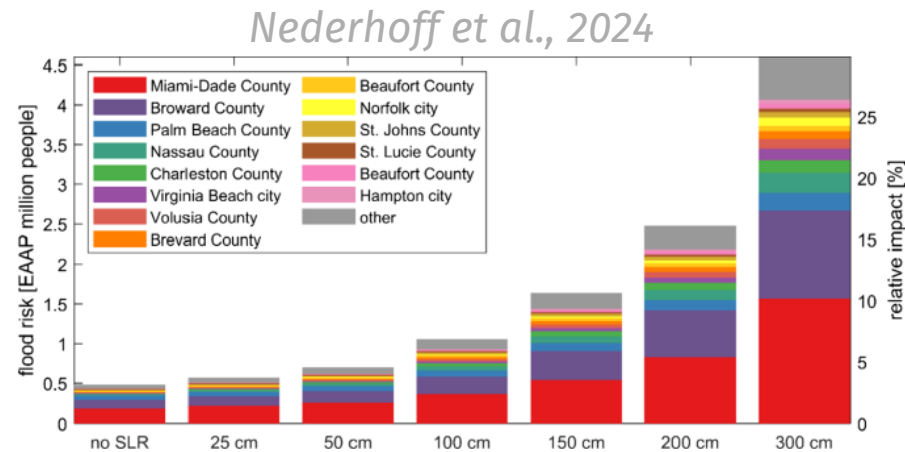
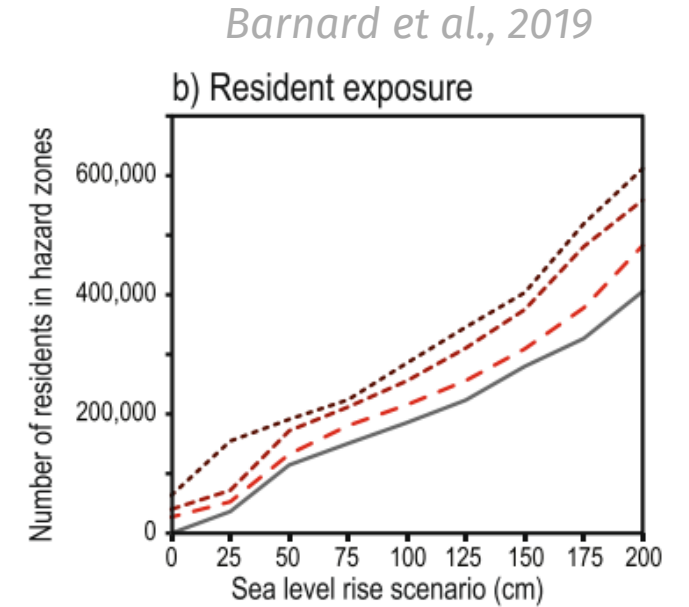
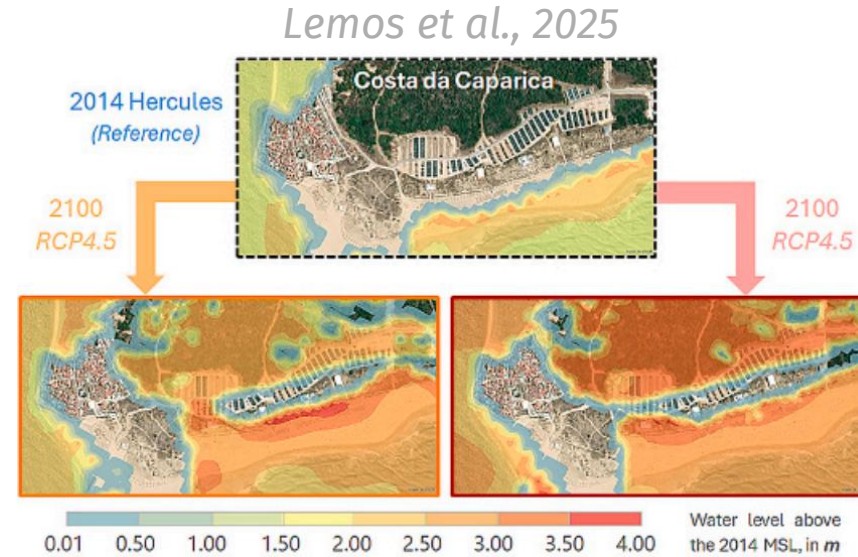
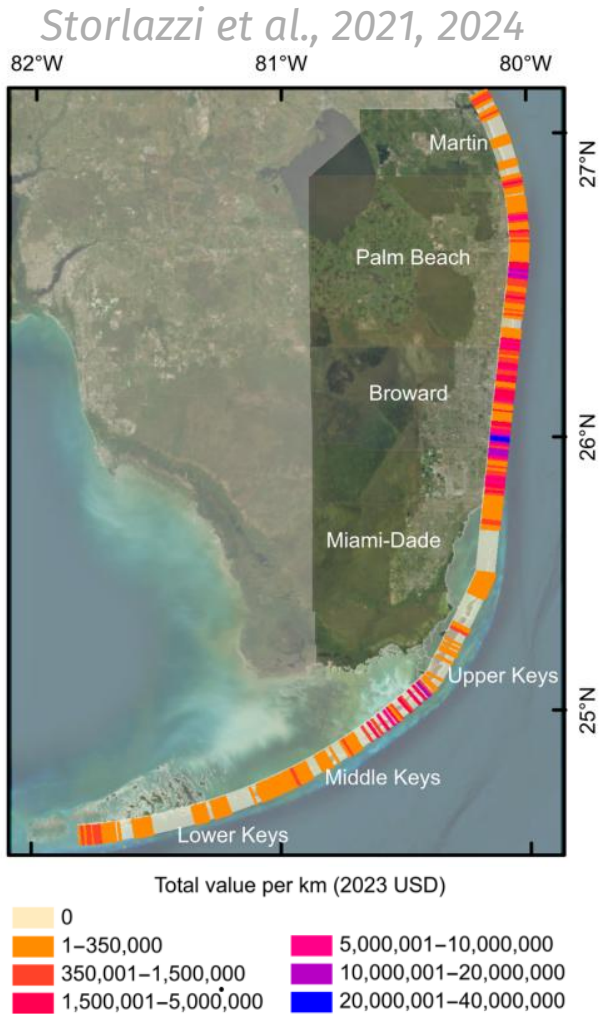


Coastal impacts along Florida's east coast induced by Irma (Cangialosi et al., 2021, Irma Post-Storm Report)

- Miami: storm surge ~1 m, wave height >7 m, erosion up to 2 m
- Residential damages in Florida counties ranged from 300-2000 million USD (Lemke and Miller, 2021)

→ Importance of assessing flood risk due to tropical cyclones under climate change

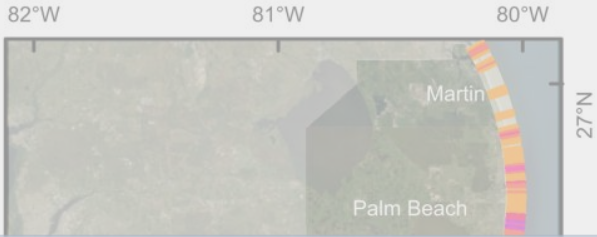
# CONTEXT: COASTAL FLOOD RISK INDUCED BY CYCLONES



⇒ Few studies integrate flooding, erosion, and their interactions with a detailed socio-economic risk assessment under climate change.

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Storlazzi et al., 2021, 2024



Lemos et al., 2025

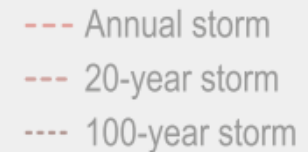
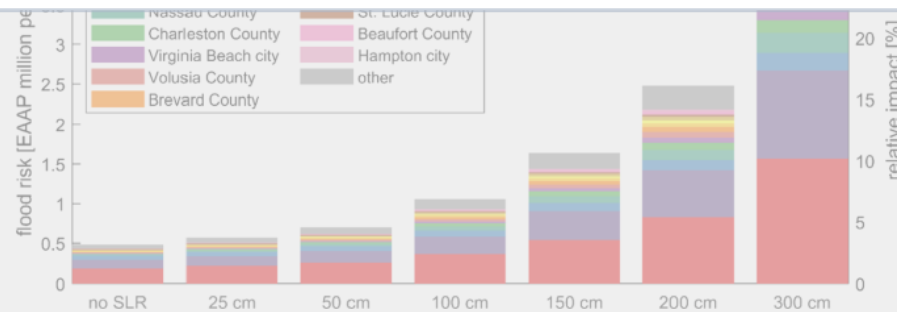
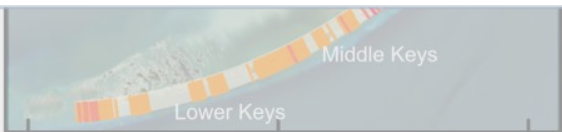


Barnard et al., 2019



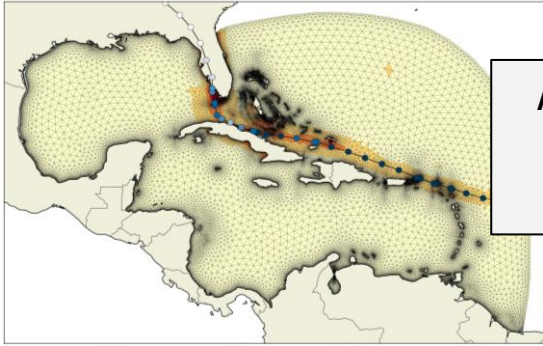
## TWO OBJECTIVES:

1. Reconstruct the hazards, impacts, and risks associated with hurricane Irma in Miami under baseline conditions
2. Assess how flood risk could change if a hurricane with the same characteristics occurred in the future



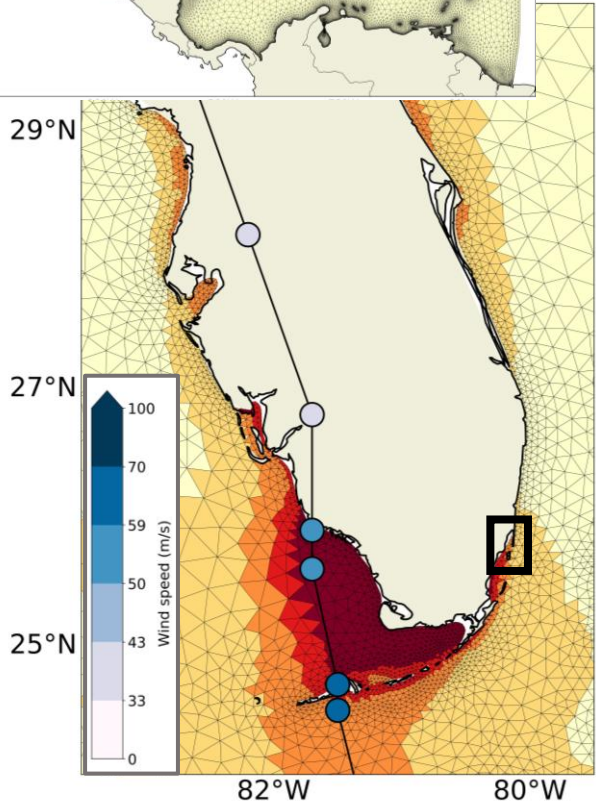
⇒ Few studies integrate flooding, erosion, and their interactions with a detailed socio-economic risk assessment under climate change.

# MULTI-SCALE MODELLING METHODOLOGY

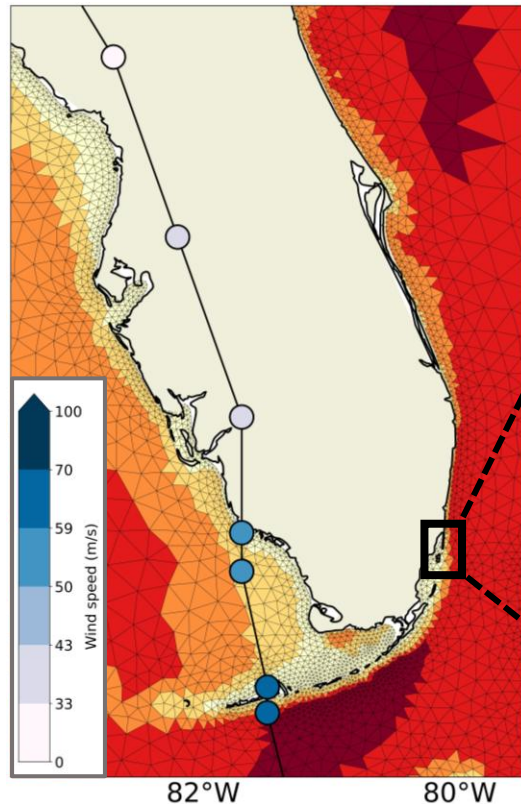


ADCIRC/ADCIRC+SWAN  
up to 3 km  
(Chaigneau et al., 2024)

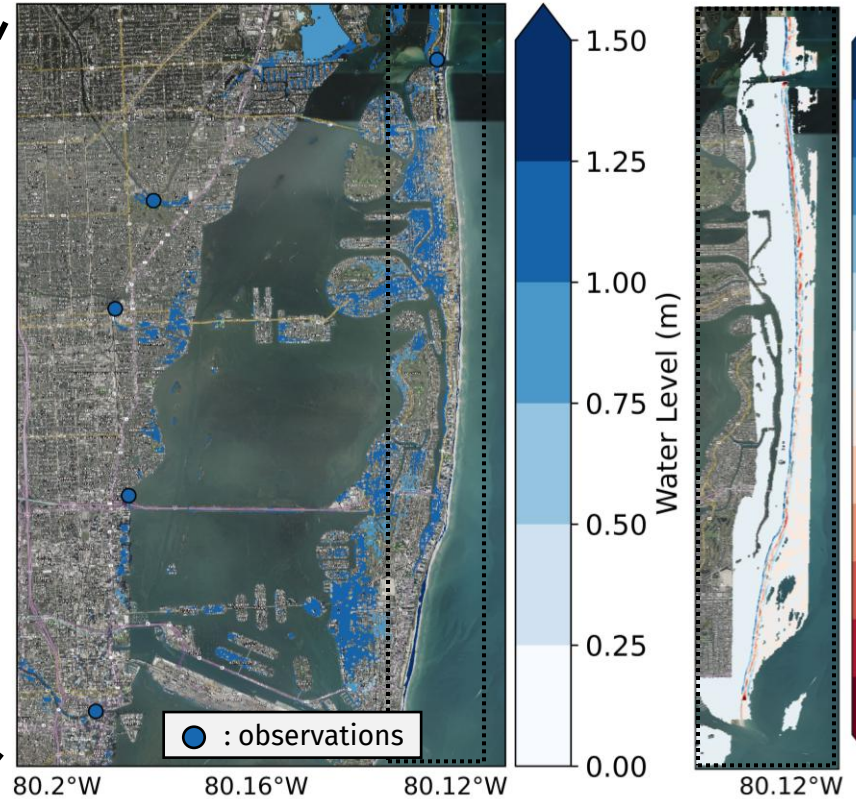
XBeach  
up to 10 m  
(Roelvink et al., 2009)



⇒ Storm surge



⇒ Waves (Hs, Tp, Dir)

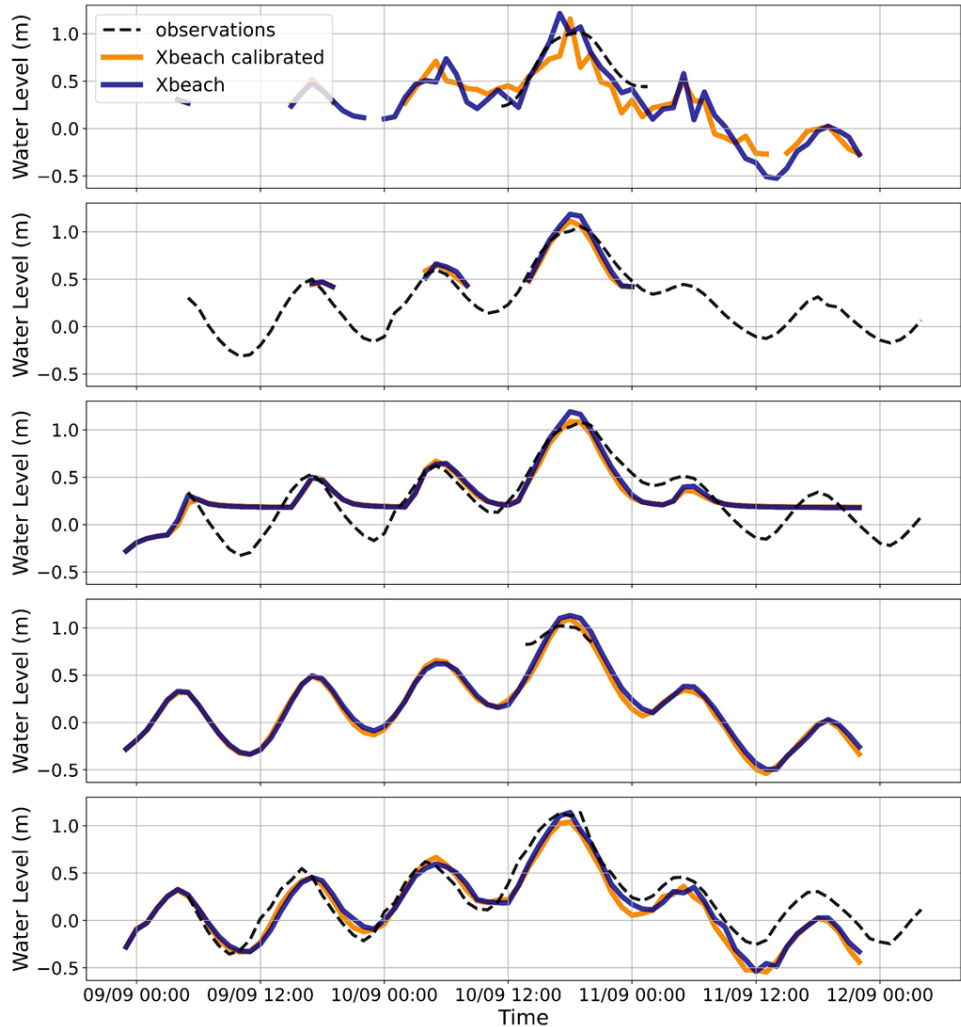


⇒ Coastal flooding, erosion, and their interactions

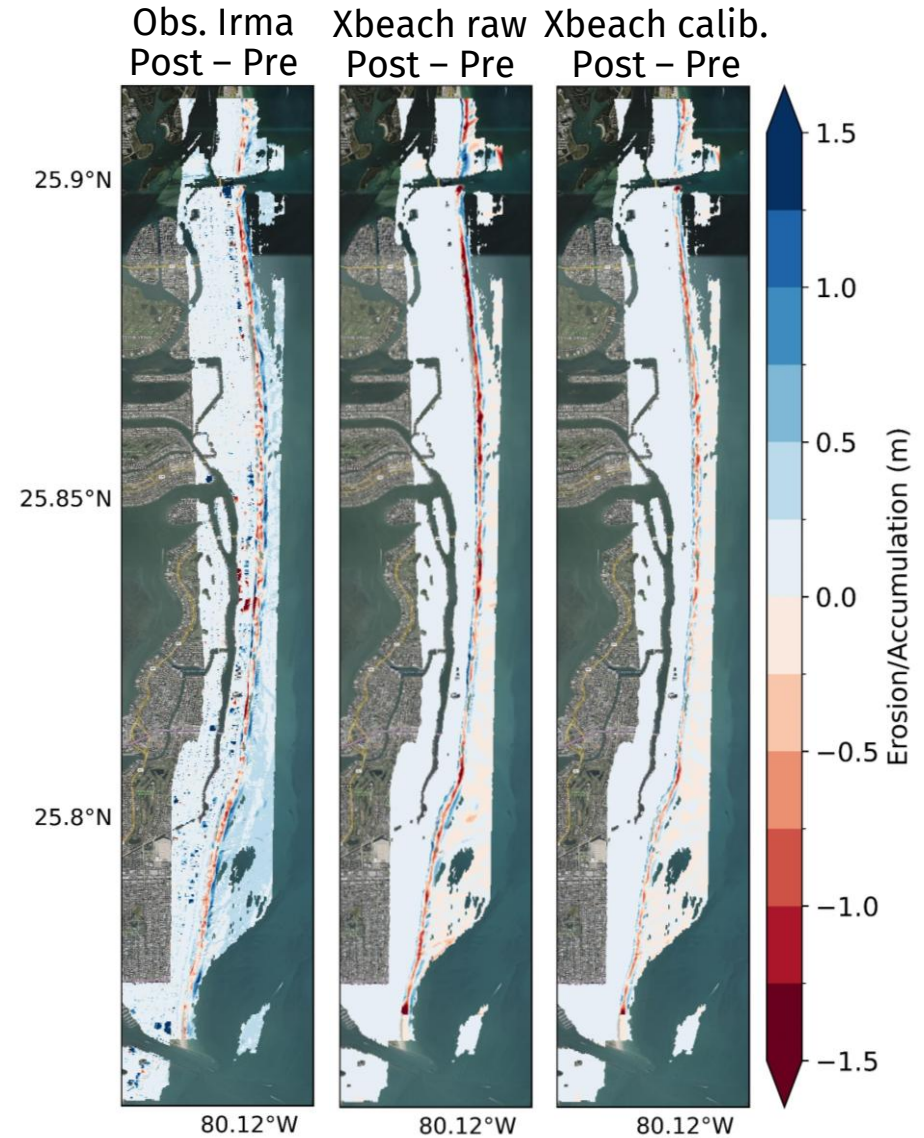
+ Tides from nearest tide gauge

# IRMA IMPACTS VALIDATION: FLOODING AND EROSION

AGAINST TIDE GAUGE DATA (SFWMD), WATER LEVEL SENSORS (USGS), PRE AND POST TOPO-BATHYMETRIC MEASUREMENTS



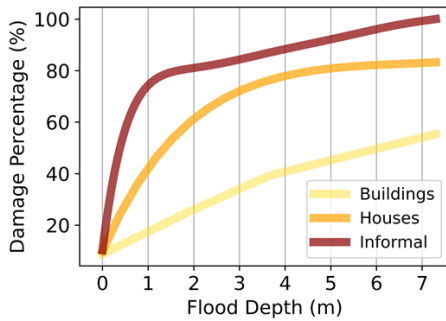
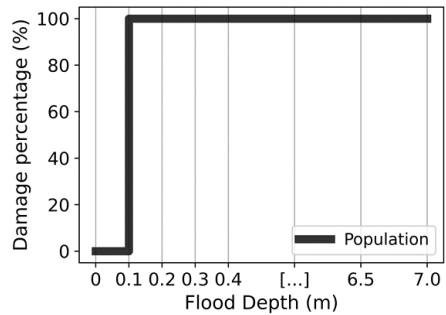
Mean absolute error on maxima = 9 cm



# IRMA FLOOD RISK ASSESSMENT

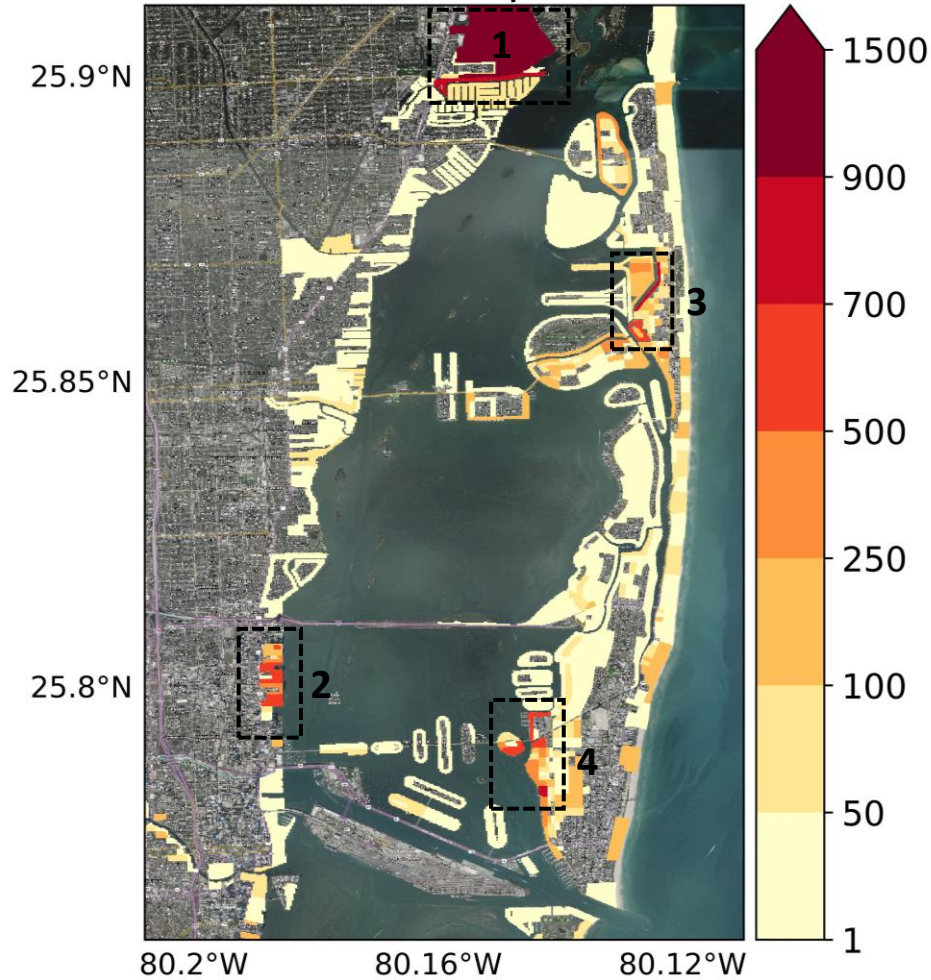
(U.S. CENSUS BUREAU DATA, DEPTH-DAMAGE FUNCTIONS FROM HAZUS)

Vulnerability depth-damage functions :



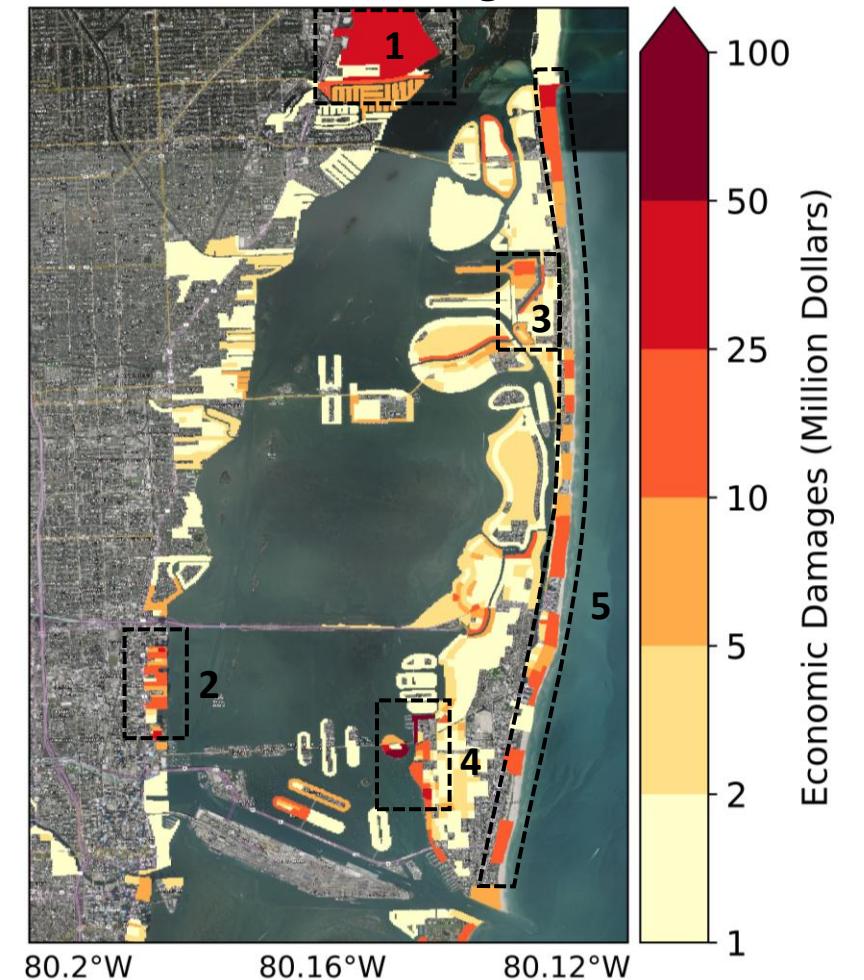
(FEMA. 2009b, Nofal and van de Lindt, 2020)

Affected Population



⇒ 35 825 pers.

Residential Damages



⇒ 1.95 billion US\$

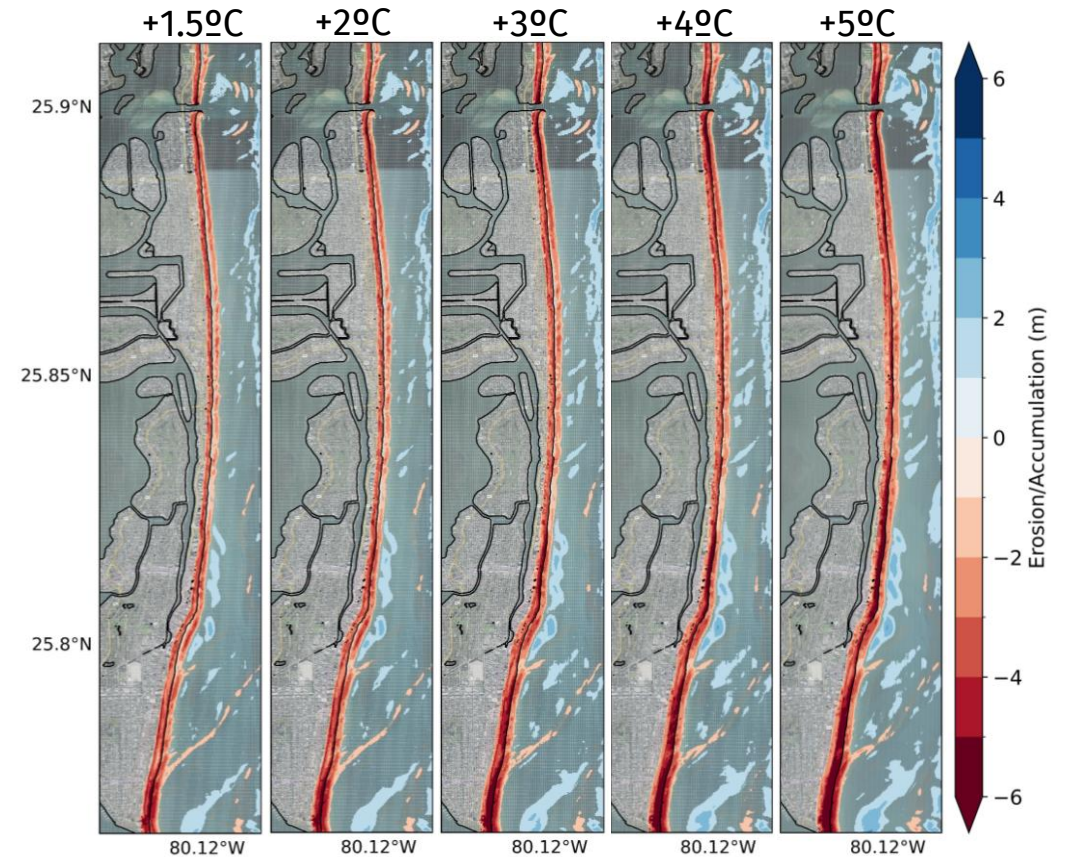
# IRMA UNDER GLOBAL WARMING SCENARIOS

## SEA LEVEL RISE (SLR), LONG-TERM SHORELINE RETREAT

1. IPCC SLR projections (Fox-Kemper et al., 2021):

Global warming level	Closest SSP	SLR (m)
+1.5°C	SSP1-2.6	+0.59
+2°C	SSP1-2.6/SSP2-4.5	+0.64
+3°C	SSP2-4.5/SSP3-7.0	+0.77
+4°C	SSP3-7.0	+0.84
+5°C	SSP5-8.5	+0.97

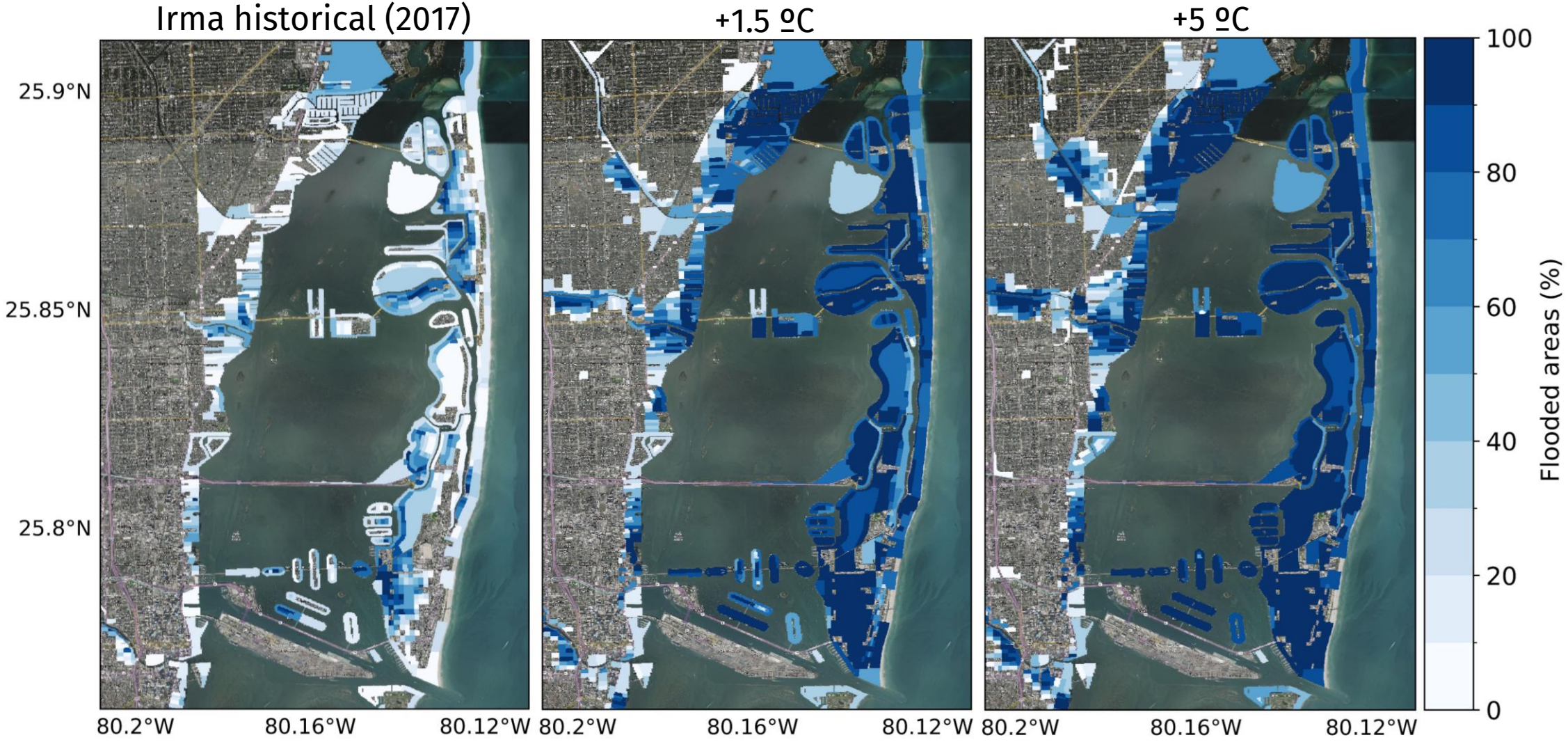
2. long-term cross-shore erosion due to SLR and updated the topo-bathymetry:



Obtained with ShoreTrans translation model  
(McCarroll et al., 2021)

# IRMA UNDER GLOBAL WARMING SCENARIOS

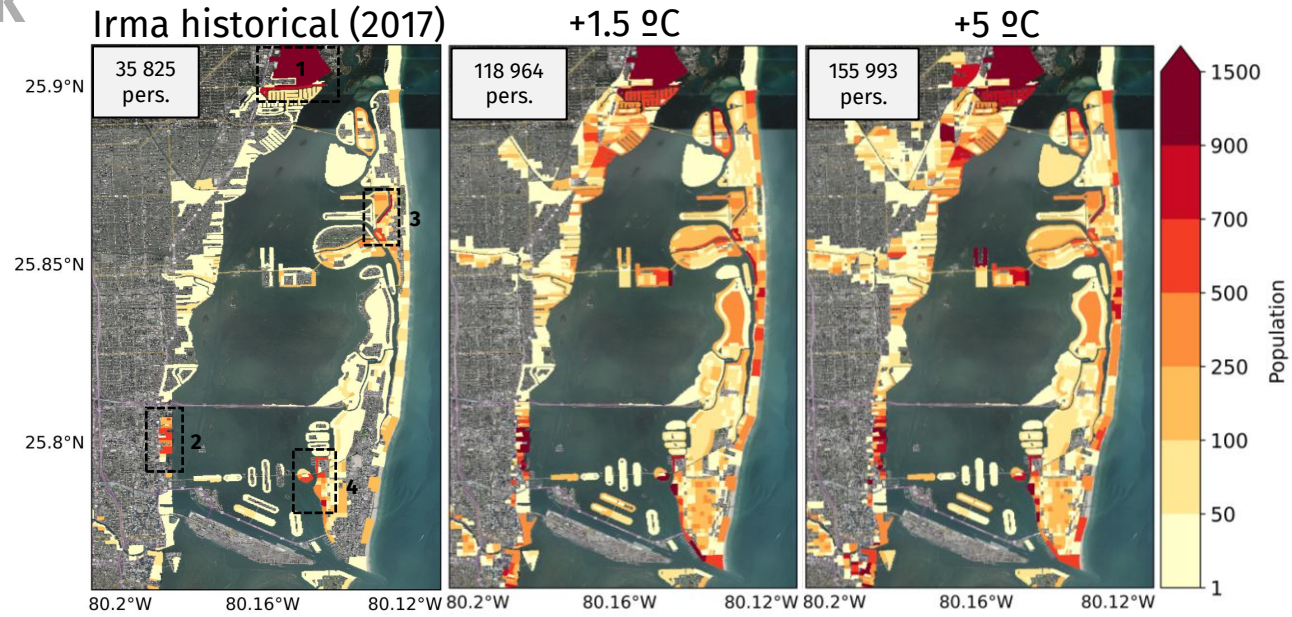
## PERCENTAGE OF FLOODED AREAS



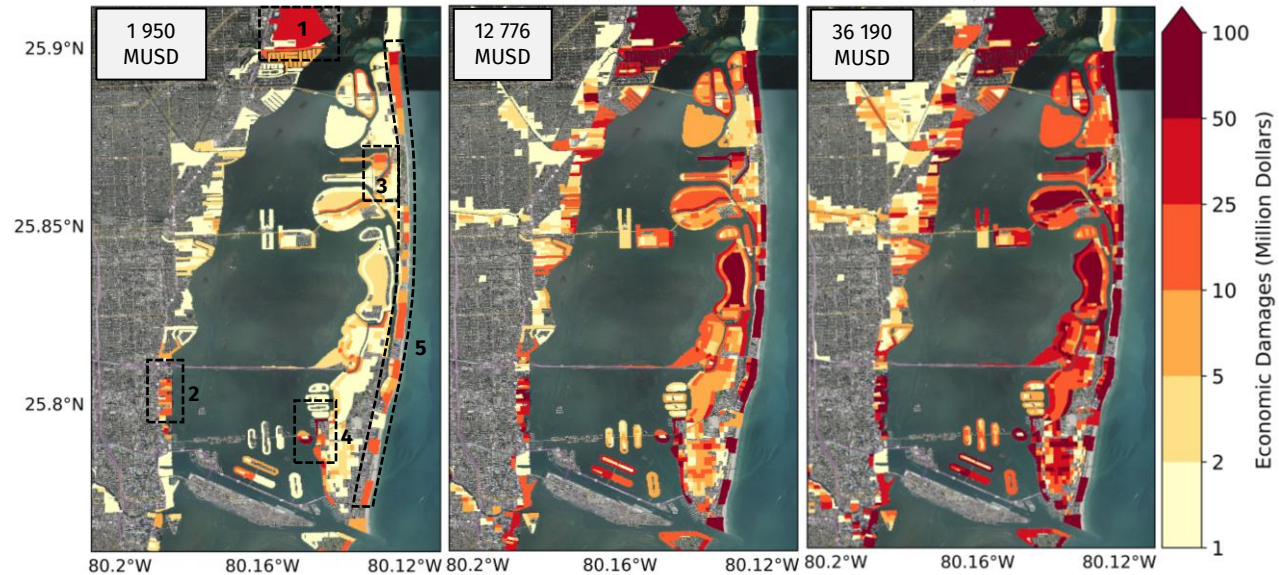
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## CHANGES IN FLOOD RISK

Affected Population

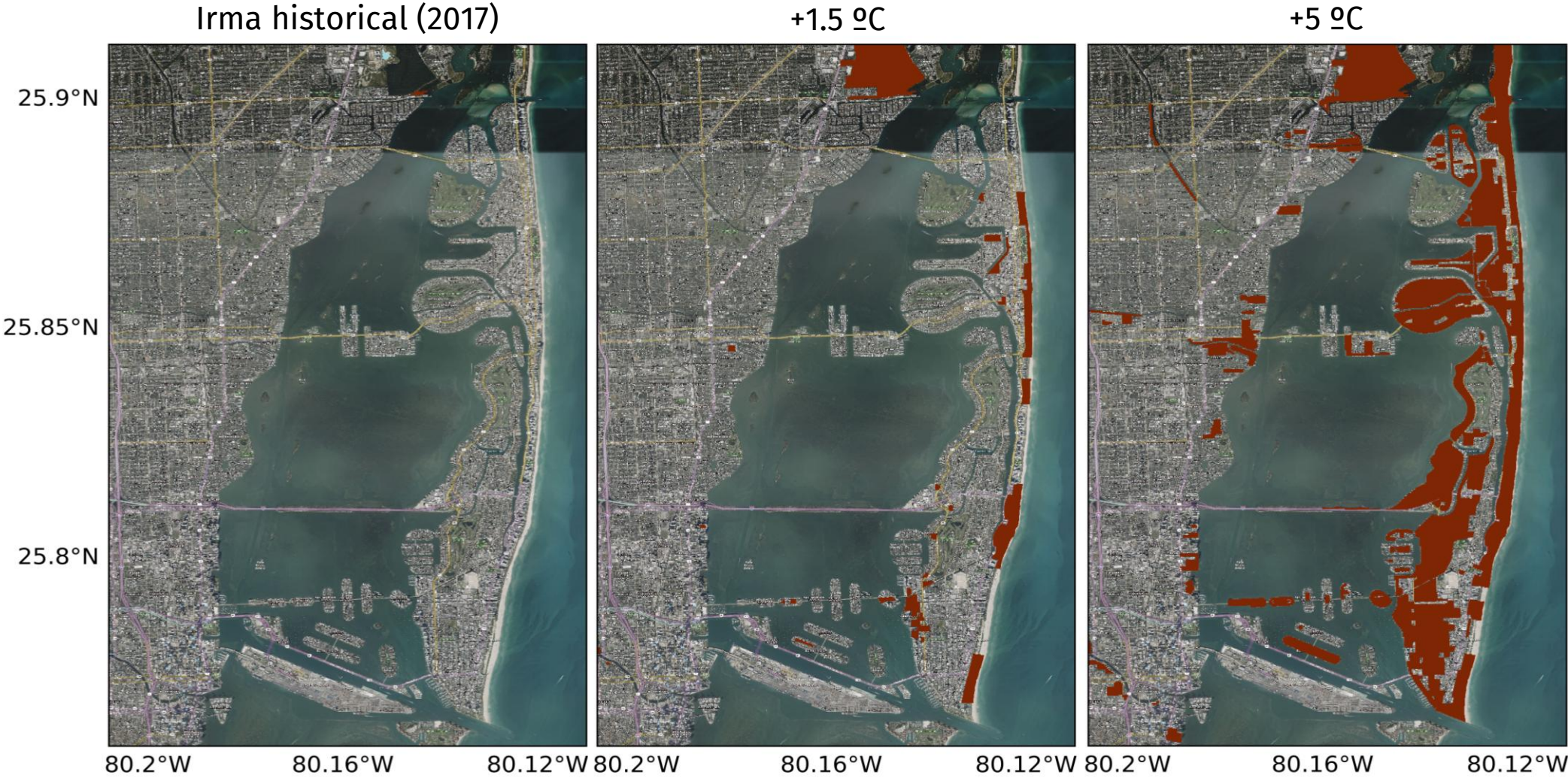



Residential Damages



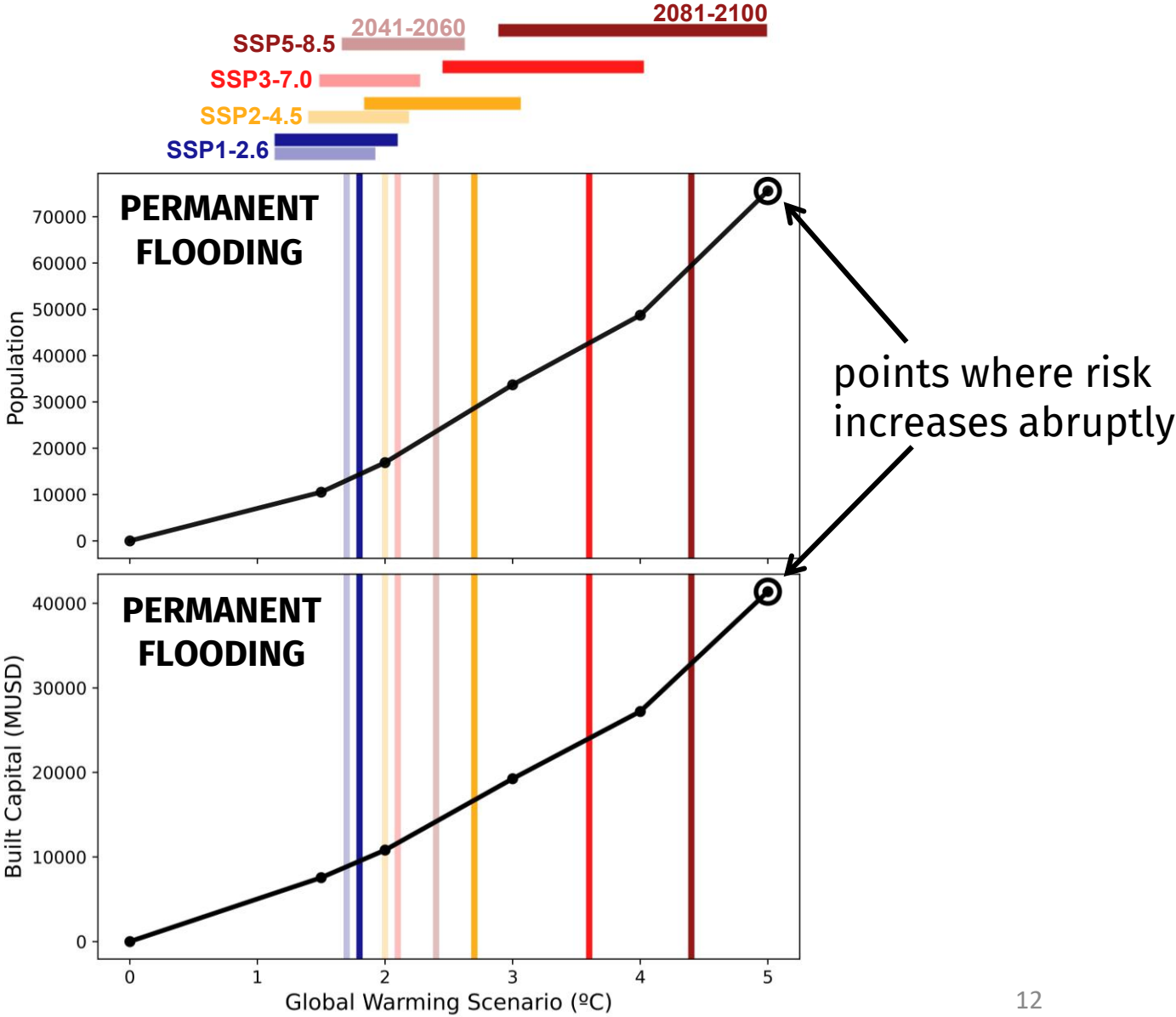
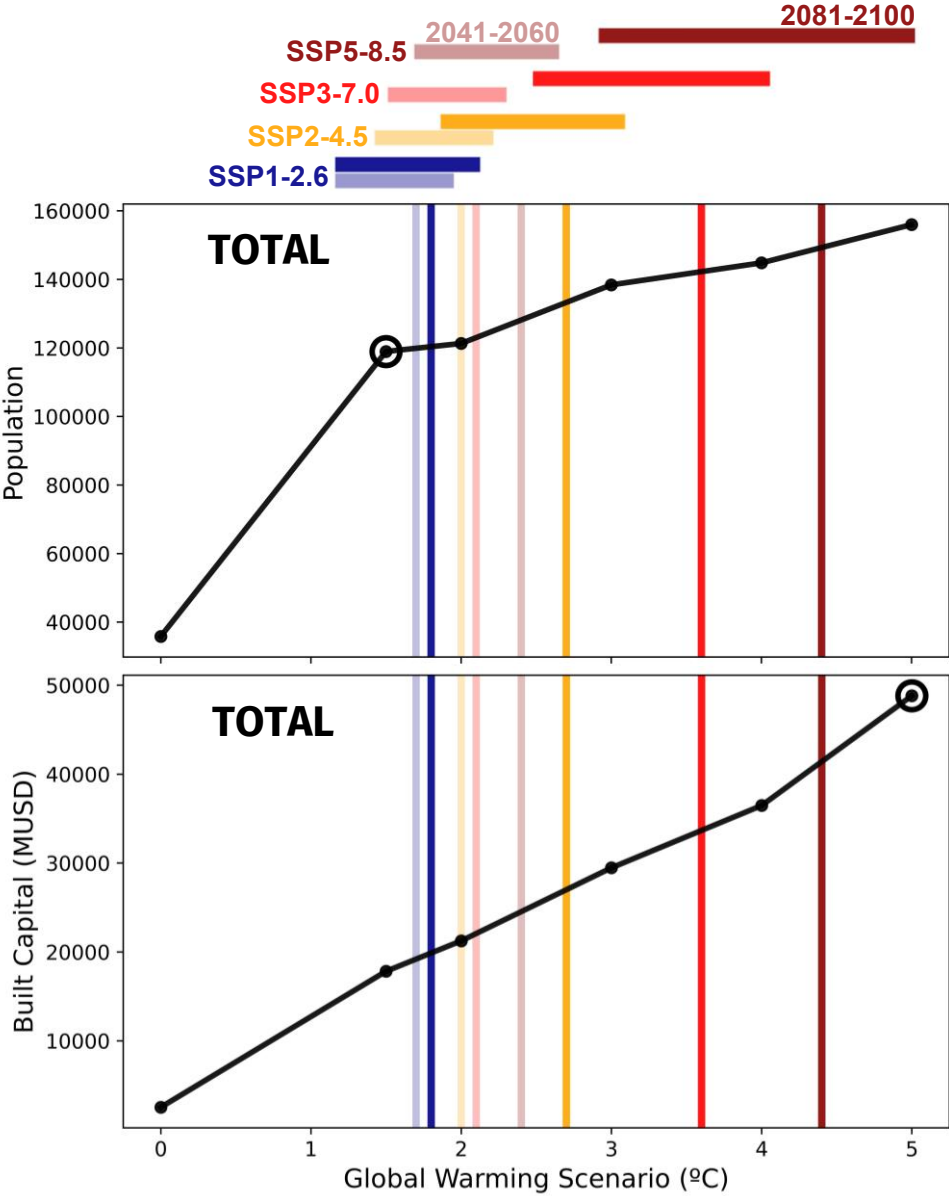
# IRMA UNDER GLOBAL WARMING SCENARIOS

## PERMANENT FLOODED AREAS



 : permanent flooded areas due to SLR

# NON-LINEAR FUTURE CHANGES IN FLOOD RISK



# CONCLUSIONS

- **Multi-scale modelling approach for reconstructing Hurricane Irma:**
  - Simulation of coastal flooding, erosion and their interactions
  - Assessment of flood risk: ~36,000 affected people and 2.5 billion US dollars in economic damages
- **Changes in coastal flood risk under higher sea level conditions** of a hurricane with the same characteristics as Irma:
  - Escalating coastal flood risk: projected to increase nonlinearly
  - Affected population: Sharp rise at +1.5 °C global warming, as even modest SLR surpasses the critical vulnerability threshold.
  - Economic losses: Rise more gradually until nonlinear rise at +5 °C global warming, due to permanent inundation of Miami Beach



## **More analyses in the paper !**

- Desegregation of social categories for flood risk
- Commercial and Industrial economic damages
- Composite risk index that integrates population density and vulnerability with built capital across residential, commercial, and industrial sectors

***Thank you !***  
***chaigneua@unican.es***

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